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TECHNICAL NOTE

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REPEATABILITY OF THE OVER-ALL ERRORS OF AN AIRPLANE ALTIMETER INSTALLATION IN LANDING-APPROACH OPERATIONS

By William Gracey and Joseph W. Stickle

Langley Research Center
Langley Field, Va.

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REPEATABILITY OF THE OVER-ALL ERRORS OF AN AIRPLANE ALTIMETER INSTALLATION IN LANDING-APPROACH OPERATIONS

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SUMMARY

Flight tests have been conducted to determine the repeatability of the over-all altimetry errors in the landing-approach condition of two sensitive altimeters (Air Force type C-12) installed in the cockpit of a transport airplane and of four precision altimeters (Air Force type MA-1) installed in a photo-observer. Data were obtained through a speed range of 62 to 100 knots during 42 landing-approach operations conducted on four different days.

The results of the tests show that the repeatability errors of the two sensitive altimeters are ±35 feet and ±39 feet. These errors are of the same order as the maximum repeatability error measured in previous tests of eleven airplanes of the same type. For each of the four flights of the present tests the mean values of the data obtained with the two sensitive altimeters shifted by relatively large amounts, apparently because of the interaction of the stability and aftereffect-recovery characteristics of the instruments.

For concurrent measurements of the over-all errors of the four precision altimeters, it is concluded that for comparable installations, the repeatability errors measured with these altimeters would be smaller than those measured with the sensitive altimeters.

INTRODUCTION

In a previous investigation (ref. 1) the results of a series of tests to determine the over-all altimetry errors of airplanes in the landing-approach condition were reported. For landing-approach operations, the over-all altimetry error is defined as the difference between the altimeter indication (with the barometric dial set to the current altimeter setting) and the correct pressure altitude at the elevation of the airplane.

The original objective of the investigation of reference 1 was to obtain a statistical measure of the errors of the service installations of a large number and variety of aircraft during routine landing operations. Since the errors of a number of these airplanes were determined in two or more landing approaches, however, it became possible to obtain also a measure of the repeatability of the errors of an installation in a particular airplane and of the installations of a given class of airplane. Of the aircraft tested in the original investigation, repeated measurements were obtained with 49 airplanes, representing 16 types of civil and military aircraft, during 198 landings. The repeatability errors of these installations, defined as one-half the difference between the minimum and maximum errors measured in two or more landings, were found to have an average value of ±25 feet; the repeatability error of one airplane installation was found to be as high as ±60 feet.

In view of the magnitude of these errors, a second investigation was undertaken to study the repeatability errors on one airplane. The aircraft chosen for these tests was a transport airplane, of a type for which a large number of measurements had been obtained in the original investigation. In that series of tests the repeatability errors, based on tests of 11 airplanes in 35 landings, varied from ±3 feet to ±40 feet. The present paper reports the results of tests of one airplane of the same type during 42 landing-approach operations. Data were obtained from two sensitive altimeters (Air Force type C-12) installed in the cockpit and from four precision altimeters (Air Force type MA-1) installed in a photo-observer.

APPARATUS AND TEST METHOD

The apparatus and test method used for the measurement of the over-all altimetry errors in the present investigation were the same as those used in the tests reported in reference 1. A detailed description of this technique, together with a discussion of the accuracy of the method, is given in reference 1. Briefly, with this method the over-all altimetry error is determined as the difference between (1) the altimeter reading (with the barometric dial set to the current altimeter setting) when the airplane is directly over a ground station and (2) the correct pressure altitude at the elevation of the airplane as determined from the geometric height of the airplane and the existing air temperature at the ground station.

The geometric height of the airplane was determined by photographing the airplane with an aerial-type camera located at the ground station and having its optic axis aligned with the vertical. The camera was equipped with a simple sighting device by means of which the camera operator could

determine when the airplane was approximately aligned with the optic axis of the camera. (See fig. 1.) The camera record and the reading of the altimeters were synchronized by a radio signal which was transmitted by the camera operator at the instant he photographed the airplane. The ground station was located a distance from the end of a runway such that the height of the airplane above the runway was about 300 to 400 feet. In this height range the error in geometric height is about 1 foot and the error in the pressure altitude (taking into account the effects of air temperature which, for the present tests, ranged from 51° to 87° F) was on the order of 2 to 3 feet.

For the present investigation two types of aircraft altimeters were installed in a transport airplane. Two sensitive altimeters (Air Force type C-12, the type normally used in the type of aircraft tested in the present investigation (see ref. 2)) were installed on the instrument panel in the cockpit and were read by the pilot and copilot. These two instruments were connected to the lower of the two service pitot-static tubes shown in figure 2. Four precision altimeters (Air Force type MA-1 (see ref. 3)), an airspeed indicator, and a rate-of-climb meter were installed in a "photo-observer" which, for the present tests, consisted of a shock-mounted, internally lighted box in which the instruments and a single-exposure, 35-millimeter camera were mounted at one end and a mirror at the opposite end. The camera was actuated by an operator in the airplane at the instant he received the radio signal from the ground-camera operator. The six instruments in the photo-observer were all connected to the upper service pitot-static tube. (See fig. 2.) The lengths of the pressure tubing to the four altimeters were the same so that any pressure lag that developed would be very nearly the same for each instrument.

TEST PROGRAM

For any given altimetry system the repeatability errors (defined as one-half the maximum spread of the over-all altimetry errors) depend on (1) the variation of the static-pressure error with airspeed and aircraft configuration, (2) any of the instrument errors that vary in a random manner, (3) variations in the rate of descent and the altitude from which the descent is initiated, two factors that influence the hysteresis and friction lag of the altimeter and the pressure lag of the pressure-tubing system, (4) errors in the measurement and reporting of the altimeter setting by the control tower, and (5) errors in the setting of the barometric dial and in the reading of the altimeter. The repeatability errors determined by the experimental method of the present tests will, of course, also be affected by any time lag in the reading of the altimeter after the radio signal is received.

For the purpose of investigating the effects of the several sources of error noted in the previous paragraph, a test program was formulated that would encompass a reasonably wide range of the controlling factors.

In order to determine the variation of the static-pressure error with airspeed and aircraft configuration, tests were conducted throughout the speed range that might normally be used with the type of airplane used in the present investigation in routine landing-approach operations. For the lower portion of the landing speed range (62 to 73 knots) the flaps were set at 50°; for the higher portion of the landing speed range (74 to 100 knots) the flaps were set at 20°.

As a means of determining the magnitude of the random instrument errors over a short period of time, a number of landings (9 to 12) were made on a single day; for the purpose of determining the magnitude over a longer period of time (a factor that would introduce the effects of the stability error and, possibly, variations in instrument temperature), flights were conducted on four different days over a period of five months. (The stability error as used in this paper is the variation of the scale errors over a relatively long period of time or following a relatively large number of altitude cycles.)

In order to determine the effects of rate of descent and the altitude from which descent is initiated, one series of tests was made with the airplane remaining below an altitude of 1,000 feet between successive landings; in another series of tests the airplane ascended to an altitude of 5,000 feet before initiating the landing approach.

Although all of the tests were conducted at the same airport, variations in the measurement and reporting of the altimeter setting could result from the fact that the tests were conducted on four different days.

The effect of errors in setting the barometric dials and reading the instruments was taken into account in these tests by employing four pilots and two copilots for the four flights. Supplementary tests of the effect of setting the barometric dials were made with the precision altimeters in the photo-observer. In one series of tests the barometric dials of the four altimeters were set to the current altimeter setting before the flight and were left at this setting for the duration of the flight; corrections for any changes in altimeter setting during the period of the flight were applied to the altimeter indications when the records were evaluated. In another series of tests the barometric dials of the altimeters were adjusted by the operator of the photo-observer prior to each landing.

The flight tests designed to investigate the several factors noted previously were conducted in accordance with the following schedule:

Altitude at which landing approach initiated, ft	No. of landings at low landing speed (50° flap setting)	No. of landings at high landing speed (20° flap setting)
Flights 1 and 2		
Below 1,000	3	
Below 1,000		3
5,000		3
Flights 3 and 4		
Below 1,000	6	
Below 1,000		6

For flights 1 and 2 the barometric dials of the altimeters in the photo-observer were fixed throughout the flight; for flights 3 and 4 the dials were reset prior to each landing. No data were obtained for the precision altimeters on flight 3 because of a malfunction of the camera in the photo-observer.

RESULTS AND DISCUSSION

The flight data obtained with the two sensitive altimeters installed in the cockpit are presented in figure 4, and the data obtained with the four precision altimeters installed in the photo-observer are presented in figure 5. In these figures the over-all altimetry errors are plotted against the indicated airspeed measured by the airspeed indicator in the photo-observer. The data obtained on each flight are grouped according to the two airspeed-range - airplane-configuration conditions: low landing speed range (50° flap setting) and high landing speed range (20° flap setting). The data points are not distinguished according to rate of descent or the altitude from which the descent was initiated because an analysis of the variation of the over-all errors with these factors showed no consistent trends; any effects which may have been present were apparently masked by the effects of other variables discussed in this paper. Similarly, no measurable difference could be detected between the over-all errors measured with the precision altimeter when the barometric dials were fixed throughout the flight and when the dials were reset prior to each landing approach.

As shown by the data in figure 4, the spread of the over-all errors measured with the pilot's altimeter is 50 feet for the low speed condition and 70 feet for the high speed condition; the spread measured with

the copilot's altimeter is 62 feet for the low speed condition and 77 feet for the high speed condition. For the combined low and high speed conditions, the repeatability error of these installations is ±35 feet as measured with the pilot's altimeter and ±39 feet as measured with the copilot's altimeter. These values are of the same order as the maximum repeatability errors (±40 feet) measured on the 11 transports referred to in the Introduction. Although these errors might appear large, the procedures of reference 4 permit the altimeter indication to deviate from the field elevation by ±75 feet when the barometric dial is set to the reported altimeter setting; therefore, the values of repeatability determined in these tests are within the limits considered acceptable by current military standards for the errors of service altimeters (exclusive of installation errors).

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The lines shown in figure 4 denote the average value of the data obtained on each of the four flights. Although these averaging lines do not necessarily represent the variation of the error of the static-pressure installation with airspeed, the static-pressure errors of both the lower and upper static-pressure tubes are assumed to be constant throughout the lower and higher portions of the landing speed range for the purpose of evaluating the data obtained in the present tests.

The averaging lines are of interest in showing that the average of the over-all errors measured with both of the cockpit instruments shifted by appreciable amounts on successive flights. The values indicated by the averaging lines also show that the magnitude and direction of the shifts measured with the two cockpit instruments are not consistent. For any given altimeter installation the average value of the data obtained on successive flights could shift because of (1) temperature effects on the instrument, (2) errors in the measurement and reporting of the altimeter setting, (3) the combined stability and aftereffect-recovery characteristics of the instrument, and (4) any consistent differences in the way observers set the barometric dial and read the instrument. Aftereffect is defined as the difference between the scale error prior to a take-off and the scale error immediately following the landing; recovery is defined as the drift of the scale error from its value immediately following a landing, and the direction of this drift is toward the scale error at the time of the previous take-off.

For the present tests, the effect of instrument temperature in producing the shifts is believed to be small because of the complete lack of correlation between the direction of the shifts with the cockpit temperature for the four flights. The effects of errors in the measurement of the altimeter setting are also believed to be small because the magnitude and direction of the shifts of the average values of the over-all errors measured on successive flights are not the same for the pilot and copilot installations.

With regard to variations in the data due to differences in setting the barometric dials and reading the indicators, it may be noted that the data were obtained by four pilots and two copilots. The pilot's altimeter was positioned low on the instrument panel (where the parallax amounted to about 15 feet for both the barometric dial and the indicator) whereas the copilot's altimeter was located high on the panel (where the parallax was about 5 and 10 feet for the barometric dial and indicator, respectively). Although the parallax for the barometric dial and the indicator were in a direction to cancel, it might appear that, with different observers, some consistent differences in reading could result. However, even with a single observer (the copilot on flights 1, 2, and 4) the data are found to shift by about the same amount as those obtained by the four pilots.

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For all of the reasons noted previously it is concluded that the major cause of the shifts of the data shown in figure 4 is that due to the interaction of the stability and aftereffect-recovery characteristics of the instrument mechanism.

From the data presented in figure 5, the minimum, maximum, and spread of the over-all errors measured with the precision altimeters have been extracted and tabulated as follows:

<table>
<tr><th rowspan="3">Altimeter</th><th colspan="7">Over-all errors, ft, at -</th></tr>
<tr><th colspan="3">Low landing speed (50° flap setting)</th><th colspan="3">High landing speed (20° flap setting)</th><th>Combined low and high speed range</th></tr>
<tr><th>Minimum</th><th>Maximum</th><th>Spread</th><th>Minimum</th><th>Maximum</th><th>Spread</th><th>Spread</th></tr>
<tr><td>A</td><td>-34</td><td>-59</td><td>25</td><td>-51</td><td>-80</td><td>29</td><td>46</td></tr>
<tr><td>B</td><td>-19</td><td>-41</td><td>22</td><td>-34</td><td>-57</td><td>23</td><td>38</td></tr>
<tr><td>C</td><td>-49</td><td>-73</td><td>24</td><td>-73</td><td>-94</td><td>21</td><td>45</td></tr>
<tr><td>D</td><td>-34</td><td>-66</td><td>32</td><td>-56</td><td>-91</td><td>35</td><td>57</td></tr>
</table>

The data given in the preceding table show that the spread of the over-all errors obtained with the four precision altimeters for the low speed range is of the same order of magnitude as that for the high speed range; for the low speed range the average value of the over-all—error spread is 26 feet, and for the high speed range the average value is 27 feet.

For the combined low and high speed ranges, the maximum spread of the over-all errors measured with the four altimeters varies from 38 to 57 feet. The repeatability errors obtained with these instruments, therefore, range from ±19 to ±29 feet. The fact that the repeatability errors measured with these instruments are smaller than those measured with the cockpit instruments is due, in part, to the more precise mechanism of the precision altimeters and to the higher order of accuracy with which the precision altimeters were read from the camera records as compared with that with which the cockpit instruments were read (probably no better than ±10 feet).

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The fact that the maximum spread of the over-all errors shown in figure 5 for the combined low and high speed ranges is larger than the spread for either the low or high speed range is due to the average of the data for the high speed range being consistently lower than that for the low speed range. This difference in the average of the over-all errors for the two speed ranges is a measure of the difference in the static-presssure error of the upper static-pressure tube for the two airspeed-range - airplane-configuration conditions. The average value of this difference in the static-pressure error, as determined from the average of all of the data obtained with the four instruments, is about 20 feet.

Since the data obtained with the two cockpit instruments (which were connected to the lower static-pressure tube) do not show a consistent difference between the average values obtained from each flight for the low and high speed ranges, additional flights were made to determine the difference in static-pressure error of the lower static-pressure tube for the two speed ranges. In these tests the difference between the pressures developed by the upper and lower static-pressure tubes for the low speed range (50° flap setting) and the high speed range (20° flap setting) was measured with a differential-pressure indicator. The results of these tests showed that, on the basis of the 20-foot static-pressure difference measured for the upper static-pressure tube, the static-pressure error of the lower tube for the high speed range is about 12 feet lower than that for the low speed range. The fact that the data in figure 4 do not show a difference of this magnitude and direction in the average of the over-all errors measured with the two cockpit altimeters is apparently due to the relatively poor precision of the data obtained with these instruments.

As noted previously, the repeatability errors measured with the precision altimeters are smaller than those measured with the sensitive altimeters in the cockpit. If the precision altimeters had been connected to the lower static-pressure tube (for which the difference in the static-pressure error between the low and high speed ranges was 8 feet less than that of the upper tube), the repeatability errors obtained with the precision altimeters would presumably have been

even smaller. On the other hand, if the precision altimeters had been installed on the instrument panel and read by the pilots, the repeatability errors would, because of the larger reading errors, undoubtably have been larger than the values derived from the camera records of the photo-observer. Since the effects of these two factors would approximately cancel, the data obtained from the photo-observer installation appear to represent an approximate measure of the repeatability errors that would have been obtained had the precision altimeters been installed in the cockpit. It seems reasonable to conclude, therefore, that for comparable installations, the repeatability errors measured with the precision altimeters would be smaller than those measured with the sensitive altimeters.

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CONCLUDING REMARKS

From flight tests of two sensitive altimeters (Air Force type C-12) installed in the cockpit and of four precision altimeters (Air Force type MA-1) installed in a photo-observer in a transport airplane operating through a speed range of 62 to 100 knots during 42 landing approach operations, the repeatability of the over-all altimetry errors (defined as one-half of the maximum spread of the over-all errors) was determined as ±35 feet for the pilot's altimeter and ±39 feet for the copilot's altimeter. These values are of the same order as the maximum repeatability error (±40 feet) measured in previous tests of 11 transport airplanes of the same type as that used in the present investigation. The mean values of the data obtained in the present tests shifted by relatively large amounts on successive flights, apparently because of the interaction of the stability and aftereffect-recovery characteristics of the instruments.

From concurrent measurements of the over-all errors of the four precision altimeters installed in the photo-observer, it is concluded that, for comparable installations, the repeatability errors measured with these altimeters would be smaller than those measured with the sensitive altimeters.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., March 31, 1961.

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1. Gracey, William, Jewel, Joseph W., Jr., and Carpenter, Gene T.: Measurement of the Errors of Service Altimeter Installations During Landing-Approach and Take-Off Operations. NASA TN D-463, 1960.

2. Anon.: Sensitive Altimeters. Technical Manual - Overhaul. T.O. 5F3-4-2-3 (Formerly 05-30-17), U.S. Air Force, Mar. 15, 1946. (Rev. Apr. 1, 1959.)

3. Anon.: Pressure Sensitive Altimeters. Technical Manual - Overhaul. T.O. 5F3-3-3-3, U.S. Air Force, June 1, 1959. (Rev. July 30, 1959.)

4. Anon.: Instrument Flying - Techniques and Procedures. AF Manual 51-37, Dept. Air Force, Oct. 1953. (Rev. Feb. 1956.)

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Figure 1.- Aerial-type camera used to measure geometric height of airplane in landing-approach operations.

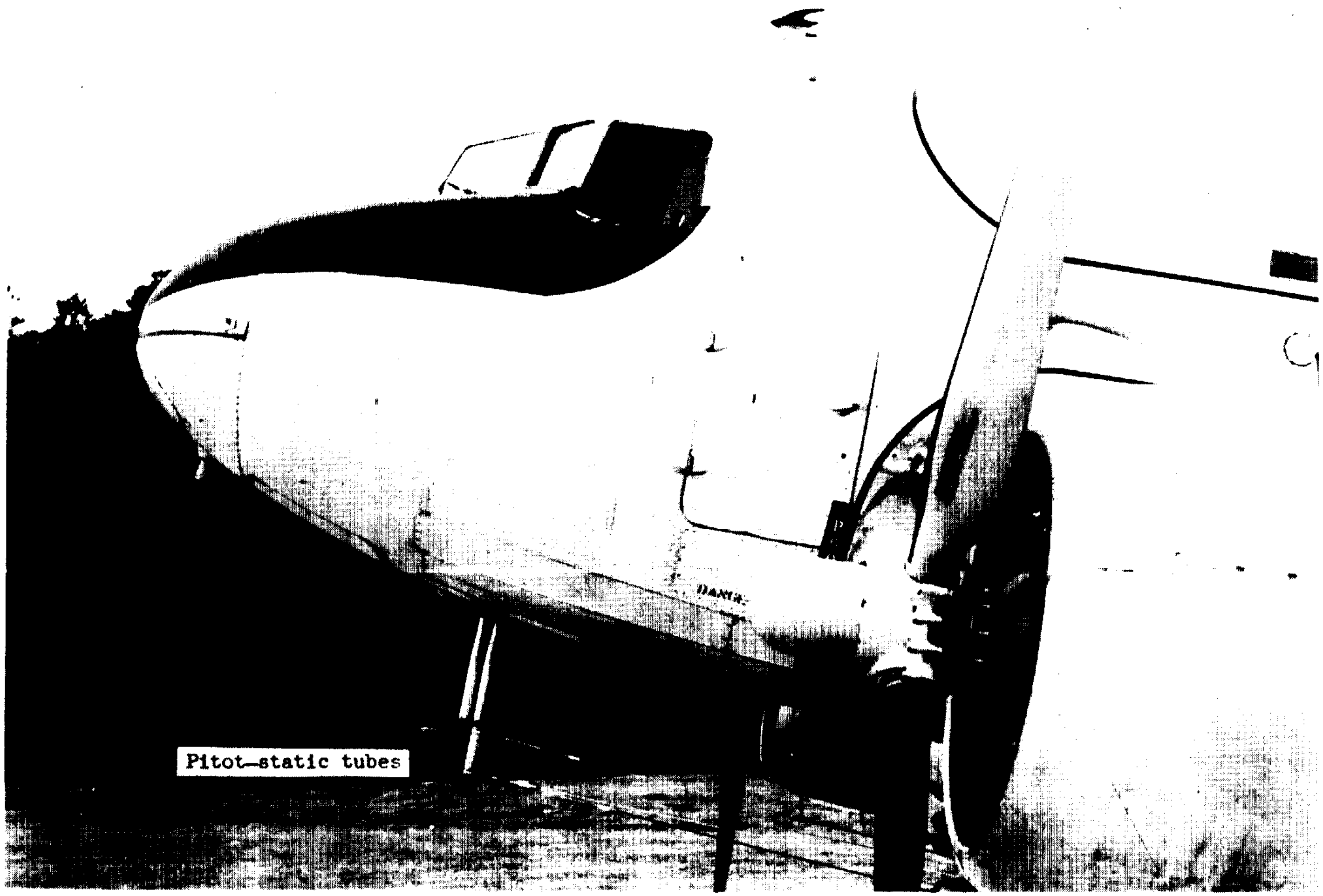

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Figure 2.- Nose section of transport airplane showing upper and lower pitot-static tubes.

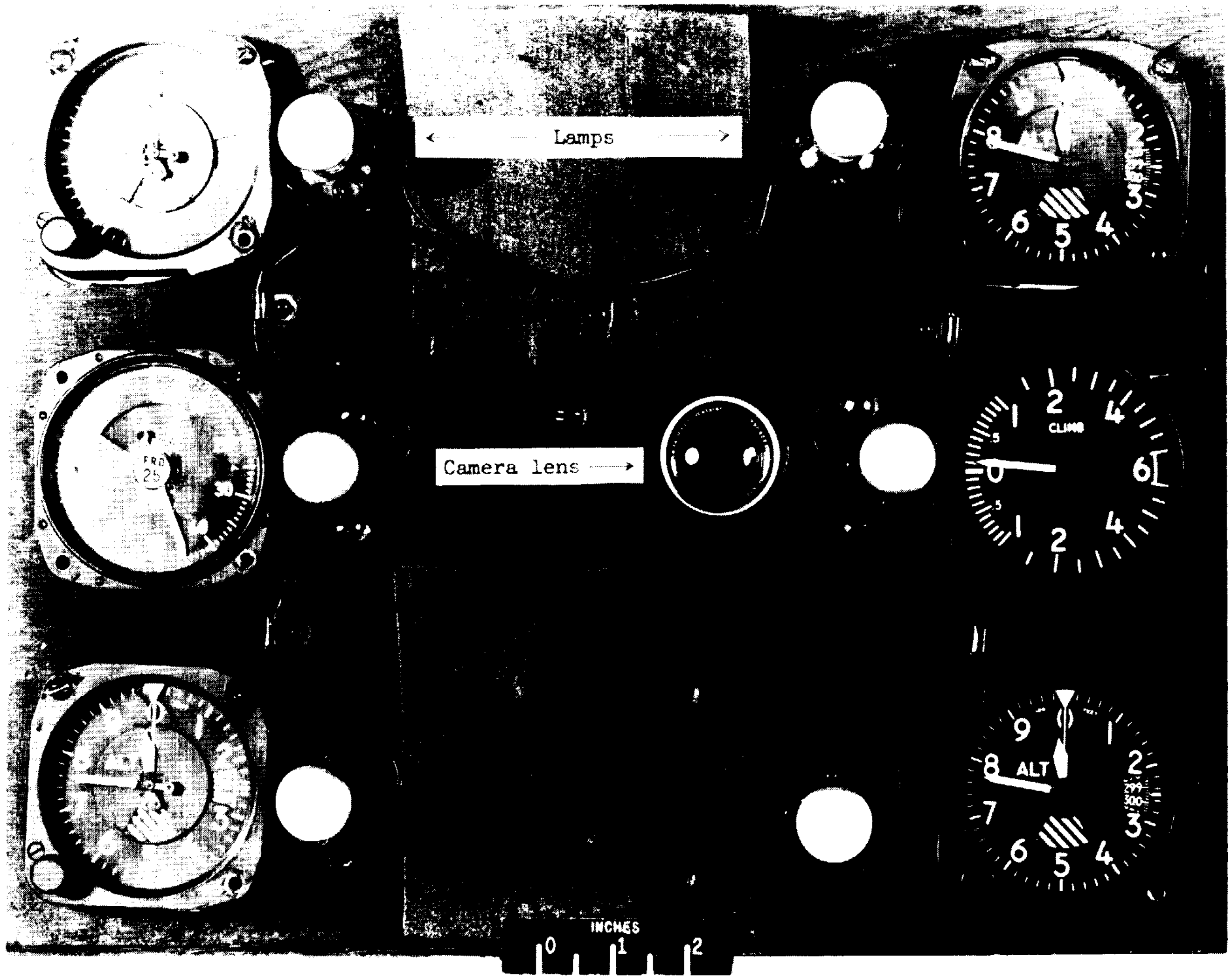

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Figure 3.- Photo-observer panel used for the measurements with the four precision altimeters.

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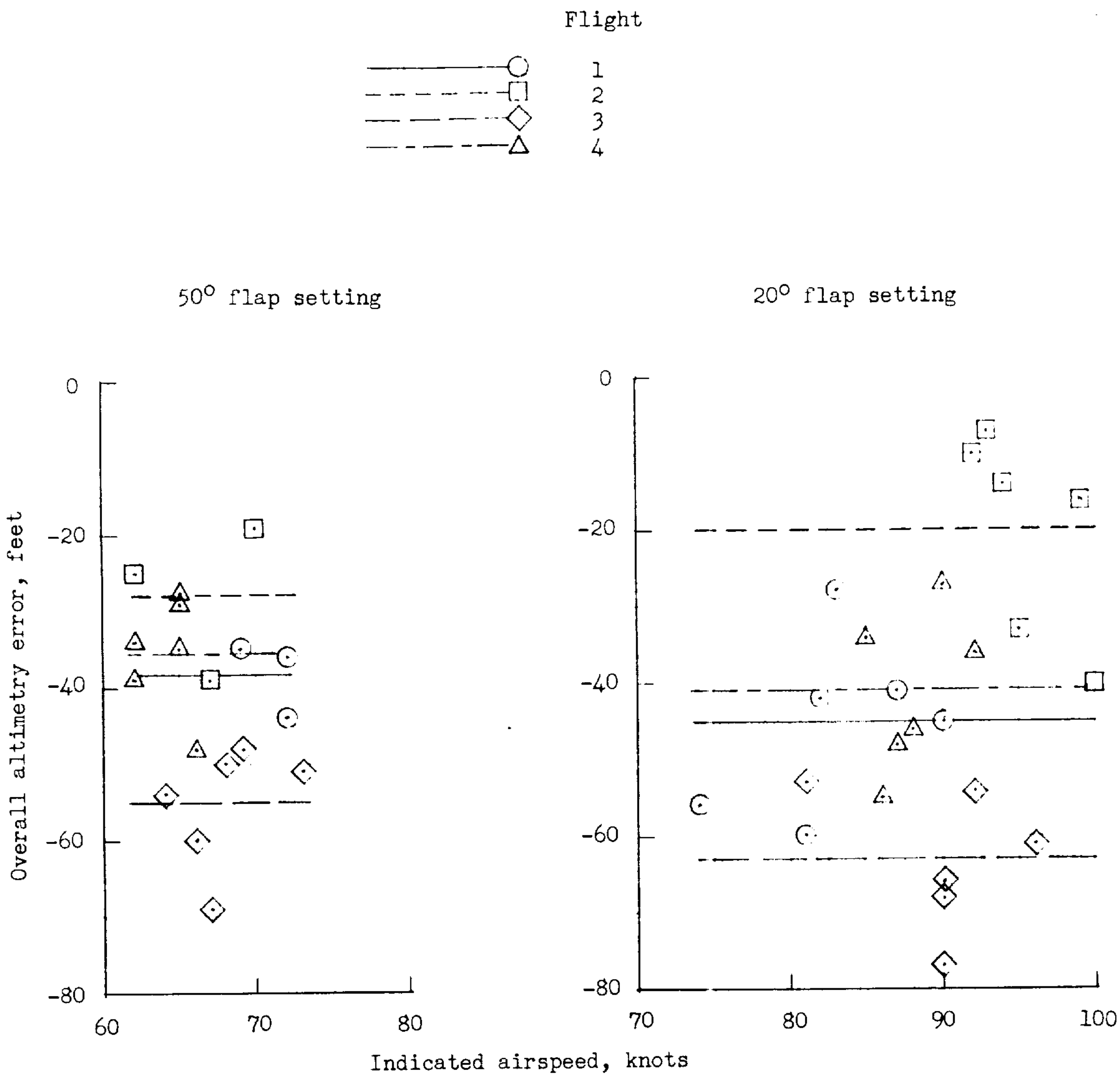

(a) Pilot's altimeter.

Figure 4.- Variation of over-all altimetry errors with indicated airspeed of the two sensitive altimeters in the cockpit.

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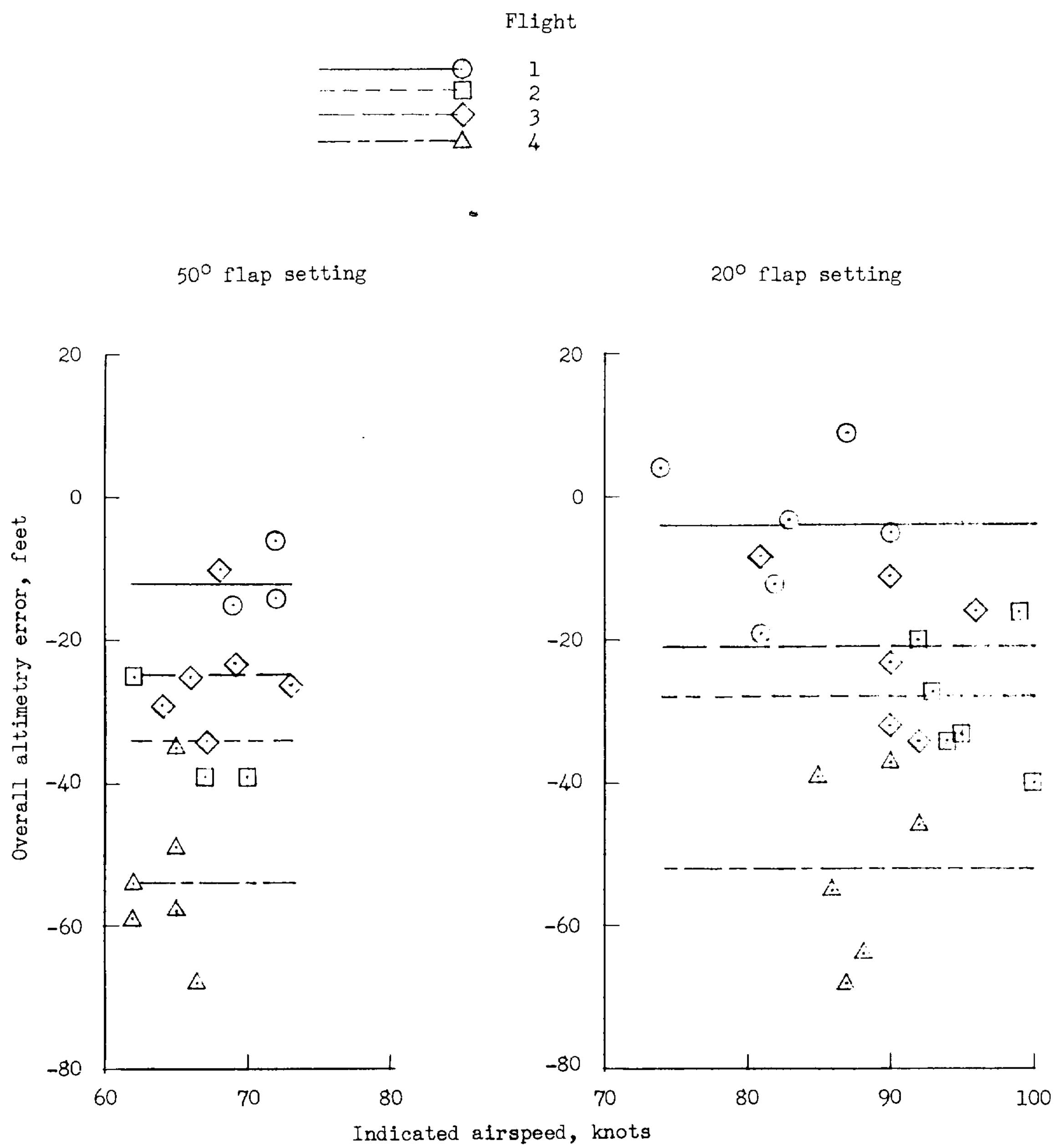
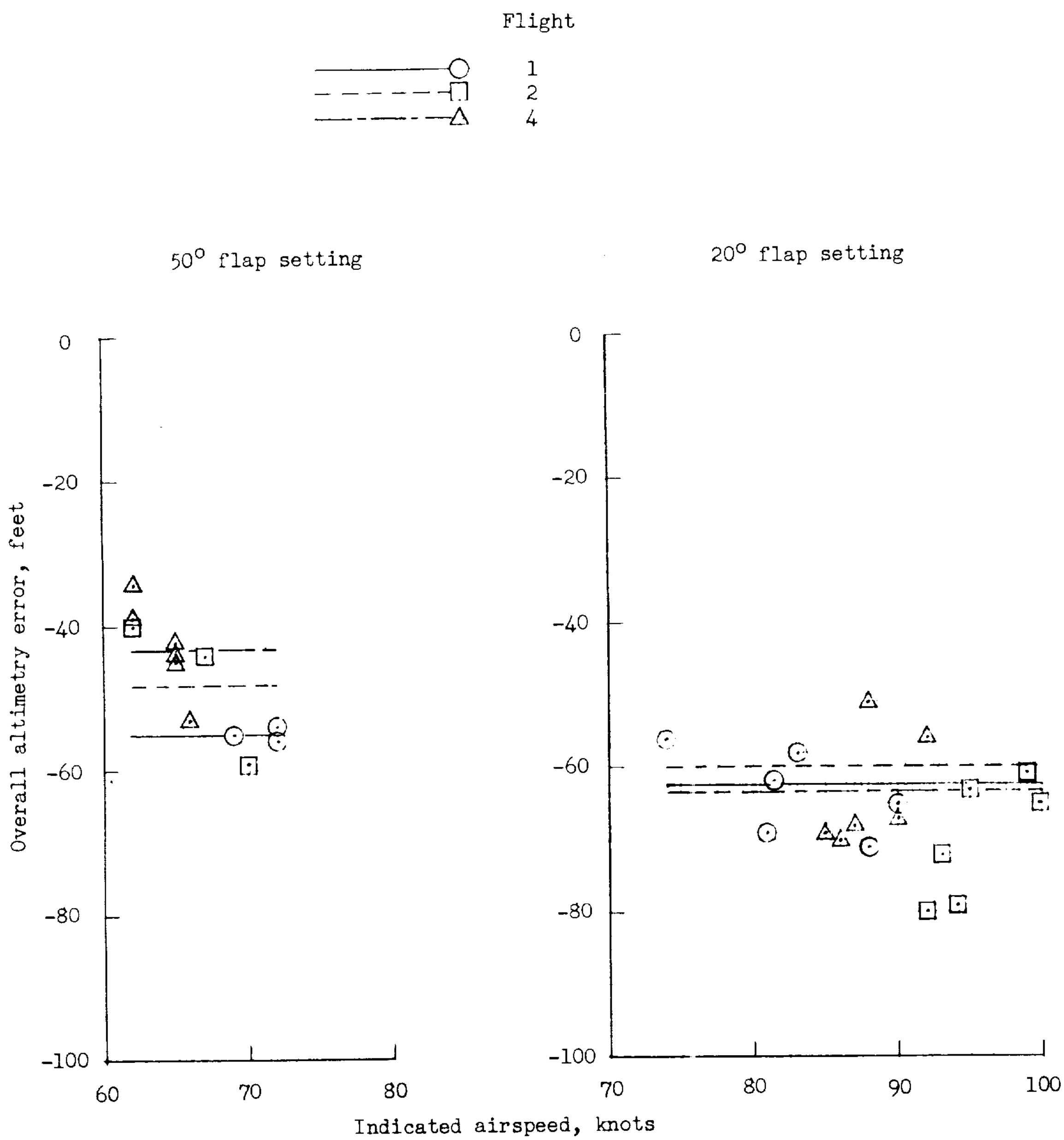


(b) Copilot's altimeter.

Figure 4.- Concluded.



(a) Altimeter A.

Figure 5.- Variation of over-all altimetry errors with indicated airspeed of the four precision altimeters in the photo-observer.

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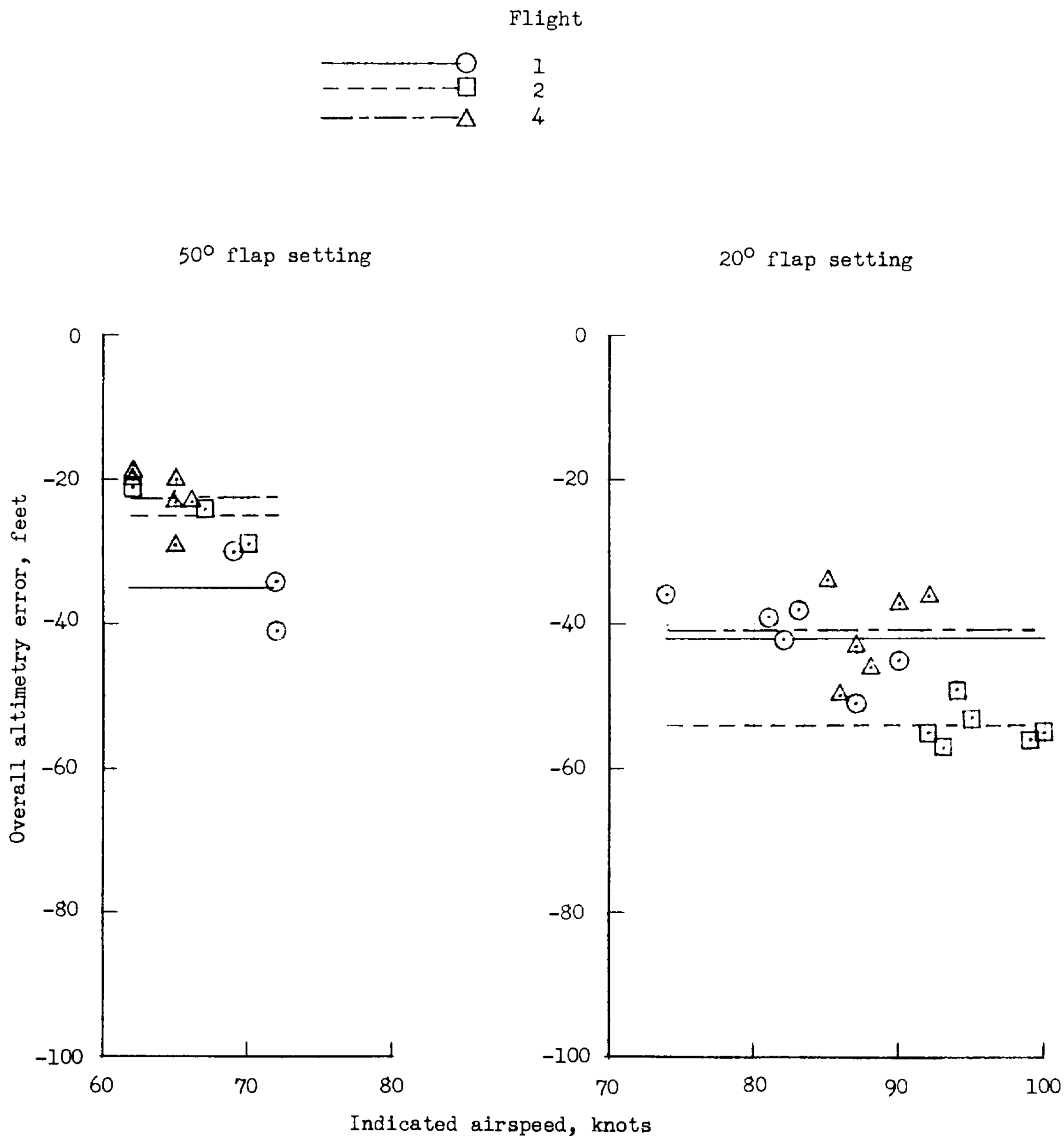
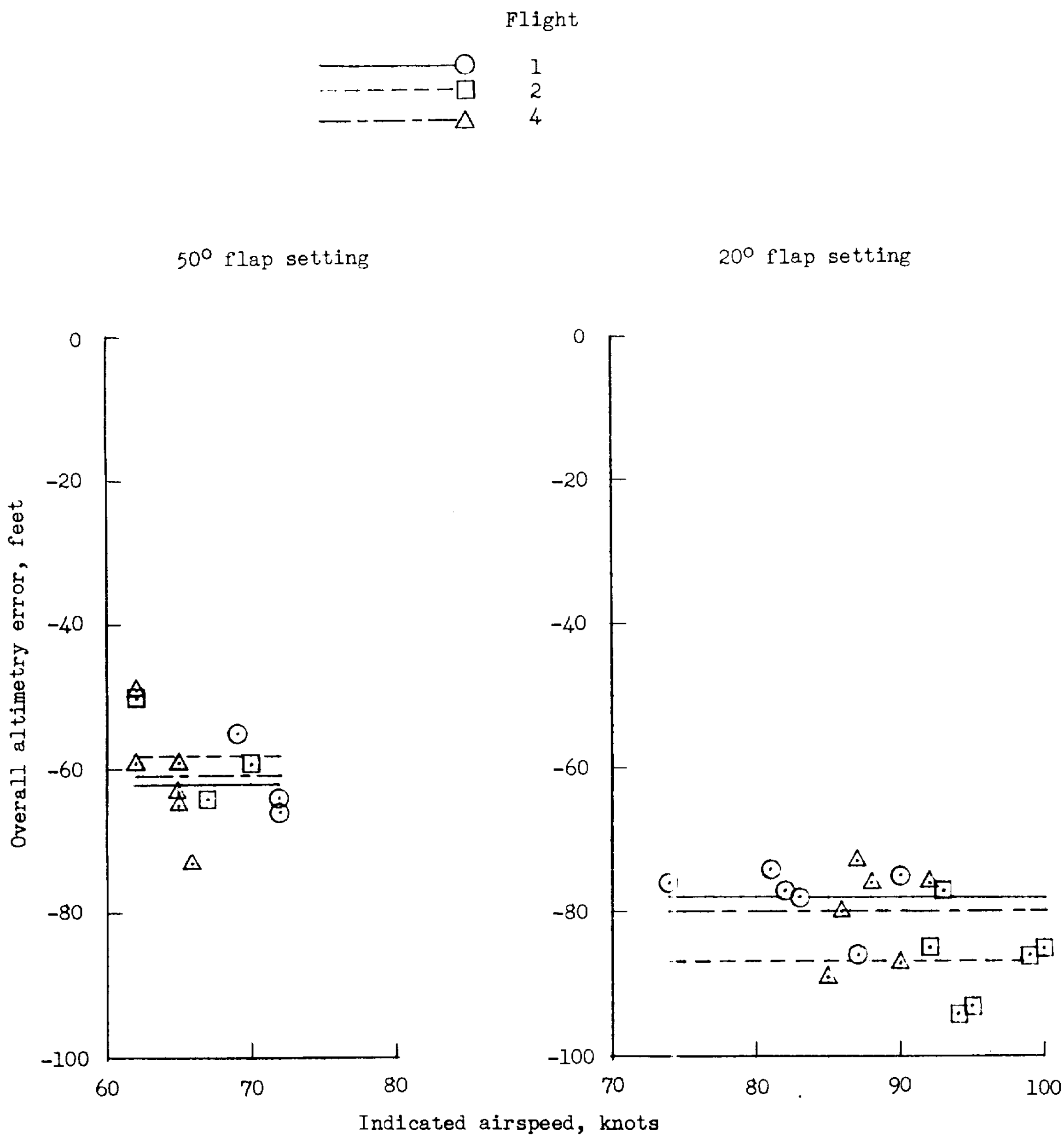


(b) Altimeter B.

Figure 5.- Continued.



(c) Altimeter C.

Figure 5.- Continued.

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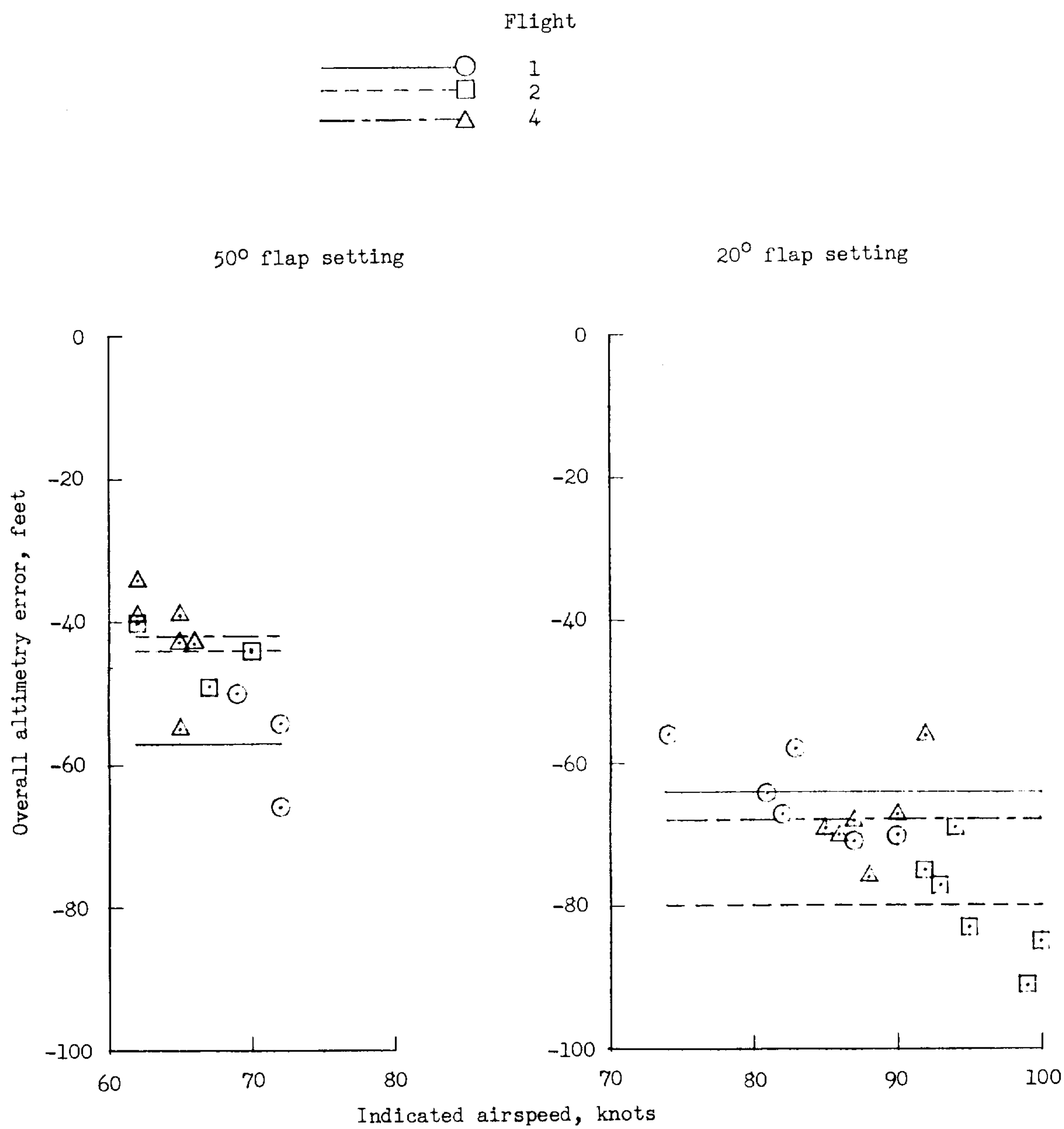

(d) Altimeter D.

Figure 5.- Concluded.